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Industrial Wastes Risk Ranking with TOPSIS, Multi Criteria Decision Making Method

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Abstract

Today, various types of industrial waste are produced in different industries to meet human demands. Growth in quantity as well as complication in quality of these wastes are followed by the advance of technology. Management of such wastes need a proper identification and comprehensive understanding of the risk, emerging after the harmful characteristics of the wastes and negatively affect the human and environment health. Wastes risk ranking systems, in this regard, links between the industrial wastes indices and mathematical method/algorithm, being able at estimation of the risk level as well as comparison between the wastes of an industrial unit based on the risk level. Complexity of the method, high computational costs and lack of proper description of waste using selected indices in former studies has led to the proposal of an applicable and flexible method. In this study, the "TOPSIS Multi-Criteria Decision-Making (MCDM) method" was developed in order for ranking the risk of various industrial wastes. Totally, a number of 9 subsidiary indices on the human health and 11 subsidiary indices on the environment health was identified and employed. Finally, the proposed waste risk ranking system was used for ranking 9 types of identified industrial waste in three industrial section. Results show that the "TOPSIS MCDM", due to the lack of complexities in method and limited computational costs, is an efficient and appropriate method for ranking industrial wastes.

Keywords: Industrial Waste; Waste Risk Ranking System (WRRS); TOPSIS Multi-Criteria Decision (MCDM) Method; Descriptive Indices of Waste.

1. Introduction

Cities of the Asia and Pacific region have accommodated 2.1 billion people, more than half of the world's urban population, while this portion will continue to grow with the growth of regional urbanization within the current century [1]. Until 2050, nearly 65% of the regional population will be urbanized, starting from 47.4% in 2014. Most of this progress will occur in cities containing below 500,000 residents (i.e. secondary cities and towns) in middle- and low-income countries. Unfortunately, these cities are conventionally provided with the least facilities to face the difficulties cussed by instant urbanization. Urbanization would leave significant tracks on all aspects of life, such as the environmental and human health. Today, human and environmental health issues caused by various types of industrial wastes are resulting from large scale production of wastes, being vast in variety and composition, as well as unfamiliarity with the waste types and complications of waste management [2]. Proper identification of waste directly affects the estimation of their risk, and preparation in order to encounter and prevent the harmful tracks of industrial waste [3, 4]. Physical, chemical, and toxicological properties as well as production volume and use patterns are demanded to identify hazards and estimate the risks resulted from industrial and other groups of wastes [5].

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At present, numerous investigations are proposed on identification of the indices and characteristics of various types of waste, according to which, waste ranking systems are introduced [6-8]. Taking look at some of the previously proposed studies in this area would suggest useful insights for rating the risk of industrial wastes as well as chemical and hazardous materials. Mitchell, R. R. et al. 2002, by assigning a score for uncertainty and another for various characteristics such as toxicity, bioaccumulation, etc. determined the relative risk of chemicals. In this system, a simple rating method without using a specified mathematical algorithm is introduced [5]. A combination of qualitatively classification in estimation of industrial chemicals risk is presented in detail in the paper (Hauschild & Brrat, 2005) [9]. Estimation of chemicals risk using qualitative methods is one of the simplest and most applicable choices a researcher might prefer to make use of, together with the numerical methods.

In this regard, Talınlı, et al. 2005, simultaneously made use of both the qualitative analysis using expressions such as “very hazardous”, “hazardous”, “typical”, etc. and the quantitative rating of the hazardous wastes risk [10]. Rajeshwar, et al. 2004, presented a procedure based on rating risk, which is used to estimate hazardous waste indices namely flammability, corrosion, reactivity and toxicity during transportation. Some of the utilized indices in this method are the volume of the waste being transported, the distance between discharge center and human population exposed to risk, etc. Indices used in this study are aimed at estimation of the risk associated to waste transportation as well as another management steps of various types of waste such as production, recycling, treatment and final disposal [11].

Using waste ranking systems based on a certain number of indices, one could estimate for every type of waste, the risk of human and/or environmental health; following that, one could take the demanding plan and measure through the entire steps including waste packaging and labelling, collection and transportation, recycling, treatment and finally disposal. Commonly, a waste risk ranking system consists of two general parts. The first part includes the selection of waste indices and characteristics affecting on the waste risk level, and the second part is the selection of algorithm/method for ranking risk [12]. Some risk ranking systems of various types of waste are almost inapplicable due to complexity and high computational costs. Most of the reason is involving complicated mathematical methods and algorithms, for instance, fuzzy theory [13, 14], Copeland's scoring method [15], Hasse diagram [16] and etc. Another reason for inapplicability of some of the ranking systems is lack of detailed and comprehensive selection of waste risk indices. In order to make progress in the limitations of some previous approaches for waste risk ranking, we focused on both uncertainty of indices (waste properties) and the numerical method to recommend an applicable and simple algorithm.

1.1. *Industrial Waste Risk Ranking (IWRR)*

Generally, applying the IWRR method includes three main research steps: (1) Collecting the existing experimental data or choosing an estimation method when the experimental data are not present; (2) regulating criteria, which, singly or together, could be used to determine scores for the identified indices; and (3) proposing an algorithm for combination and weighting the scores into a numerical ranking for each sample of industrial waste. [17] The present study, by analyzing formerly proposed waste ranking systems, is aimed at covering the main and subsidiary indices for calculation of IWRR using a simple, applicable and absolutely identified approach; and consider human and environmental health aspects.

Ab IWRR system is applicable depending on how much it is efficient, free of complexities and containing accessible and measurable indices. An IWRR and scoring method has been developed as a screening tool to provide a relative assessment of hazards to human health and the environment. The present research is aimed at following targets. The first purpose is identification and use of indices describing waste risk so that the indices include both aspects subjected to risk, i.e. human and environmental health. To reduce complexities and high computations of the waste risk ranking systems, which are the main reason of them in applicability, the TOPSIS MCDM method is employed for ranking waste risk. Some of its advantages are the possibility of quantifying and turning calculations to computer language for solving as well as simplicity of its application.

2. Methodology

In the science of Multi-Criteria Decision-Making, there are several methods in which subsidiary groups containing expenses and profit are considered [18]. One of them is The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), firstly presented by Yoon 1980 and Hwang 1981 [19]. To solve Multi-Criteria Decision-Making problems based on this concept, the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). For example, the positive ideal solution increases profit and reduces expenses, and the negative ideal solution reduces profit and increases expenses. TOPSIS method is a simple and efficient method for ranking a number of possible choices, trying to obtain the optimal solution. Numerous studies employed this method for multi-solution problems in various areas of science [20-23]. The mathematical algorithm of TOPSIS method consists of the following 7 steps:

Step 1: Establish the decision matrix (DM)

The first step in TOPSIS method involves the construction of a Decision Matrix (DM).

$$Decision\ Making\ Matrix = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} C_1 & C_2 & \dots & C_n \\ \begin{bmatrix} z_{11} & z_{12} & \cdots & z_{1n} \\ z_{21} & z_{22} & \cdots & z_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ z_{m1} & z_{m2} & \cdots & z_{mn} \end{bmatrix} \end{matrix} \quad (1)$$

Where counter i as (i=1,2, …, m) denotes the waste type and m denotes the number of identified industrial waste for ranking. Also counter j as (j=1,2, …, n) denotes the indices of each type of industrial waste describing the waste risk level in the objective index, and n is the total number of indices. Elements L_1, L_2, …, L_n represent titles and indices and A_1, A_2, …, A_n represent the industrial waste.

Step 2: Calculate a normalized decision matrix (NDM)

The normalized values in the NDM are calculated as follows:

$$N_{ij} = {z_{ij}} \Big/ \sqrt{\sum_{j=1}^{m} \left(z_{ij}\right)^2} \quad , (i=1,2,...,m) \, , (j=1,2,...,n) \quad (2)$$

Step 3: Determine the weighted DM

None of the objective indices among the industrial wastes matter equally. Thus, Shannon entropy is used to determine the relative importance of the objective indices. Finally, weighted DM is easily generated by multiplying every element of the normalized matrix columns into weight values.

$$V_{ij} = Wij * N_{ij} \quad (3)$$

Step 4: Identify the Positive Ideal Solution and (PIS) Negative Ideal Solution (NIS)

The positive ideal (A^+) and the negative ideal (A^-) solutions are defined according to the weighted decision matrix via Equations 4 and 5. below:

$$PIS = A^+ = \{V_1^+ . V_2^+ . \dots . V_n^+\}, where: V_j^+ = \{(max(V_{ij})\ if\ j \epsilon\ J); (min(V_{ij})\ if\ j \epsilon\ J')\} \quad (4)$$

$$NIS = A^- = \{V_1^- . V_2^- . \dots . V_n^-\}, where: V_j^- = \{(max(V_{ij})\ if\ j \epsilon\ J); (min(V_{ij})\ if\ j \epsilon\ J')\} \quad (5)$$

Where, J and J' are benefit and expenses attributes, respectively.

Step 5: Calculate the separation distance of each alternative (waste) from the ideal and non-ideal solution.

In order to calculate the separation distance of each alternative (waste) from the positive ideal solution (S^+) using Equation 6. is used as follows:

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(V_j^+ - V_{ij}\right)^2} \ . (i = 1.2. \dots . m) \quad (6)$$

In order to calculate the separation distance of each alternative (waste) from the negative ideal (S^-) solution using Equation 7. is used as follows:

$$S^- = \sqrt{\sum_{j=1}^{n} \left(V_j^- - V_{ij}\right)^2} \ . (i = 1.2. \dots . m) \quad (7)$$

Step 6: Measure the relative closeness of each location to the ideal solution.

For each competitive alternative the relative closeness of the potential location with respect to the ideal solution is computed by Equation 8. as follows:

$$D_i = \frac{S^-}{S^+ + S^-} \quad .(i = 1.2. \dots .m)$$
$$If\ D_i = 1 \rightarrow A_i = A^+$$
$$If\ D_i = 0 \rightarrow A_i = A^- \tag{8}$$

Where D_i varies between 0 and 1. As much as this value is close to 1 the rank of the objective alternative diminishes.

Step 7: Rank the preference order of alternatives (wastes)

According to the risk value obtained by each waste in the final level, ranking of the waste risks are accomplished. Based on the results of this method, waste with the maximum value of D_i is introduced as a high risk waste and obtain a higher rank, and vice versa.

2.1. *Shannon Entropy*

So far, multiple weighting indices have been proposed by the researchers; such as Shannon entropy [24], which is very efficient the entropy concept is well suited for measuring the relative contrast intensities of criteria to represent the average intrinsic information transmitted to the decision maker [25], conveniently it would be a proper option for our purpose. Shannon entropy is, in fact, an estimation of uncertainty in the formulated information in the Probability theory. It is a calculation method of weights through the following steps [26, 27]:

Step1: Normalize the objective indices

$$P_{ij} = \frac{X_{ij}}{\sum_j X_{ij}} \tag{9}$$

Step2: Calculate the entropy of each index

$$e_{ij} = -k \sum_{j=1}^{n} P_{ij}\ ln(P_{ij}).\ \ k = (ln(m))^{-1} \tag{10}$$

Step3: Define the value of divergence for each index

$$div_j = 1 - e_j \tag{10}$$

Step4: Calculate the normalized weights of each index

$$w_{ij} = \frac{div_j}{\sum_j div_j} \tag{11}$$

3. Results and Discussions

The ranking of alternatives is a very challenging task. The IWRR in initial phase needed very high expertise in decision making to select right project from all nine identified wastes. So the hierarchical structure of study has been constructed for the evaluation criteria as shown in Figure 1.

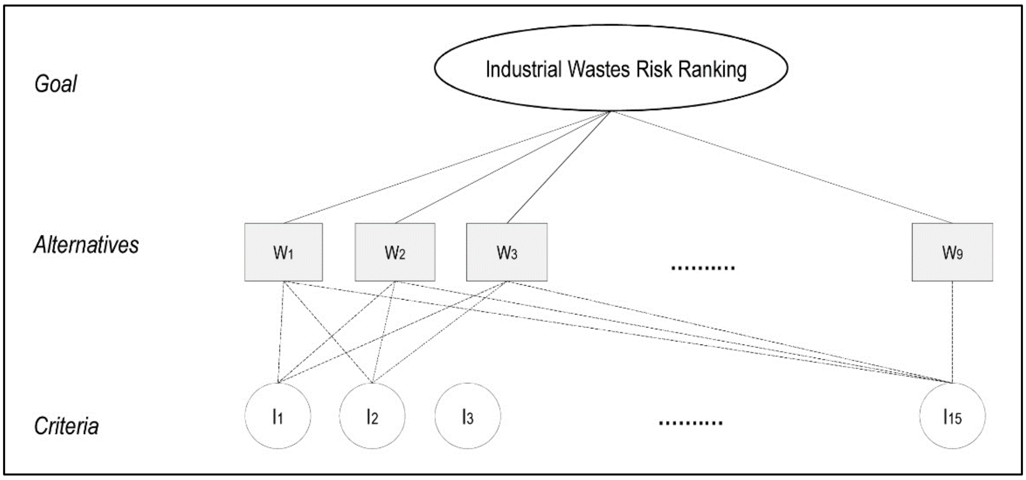

Figure 1. Hierarchical structure of study

In order to use TOPSIS method for IWRR, and toward achieving the primary purpose of the study, firstly the indices and characteristics affecting the IWRR were identified and presented in Table 1. The approach used to select the indices were the separation of risk between human health and environment. This leads to the risk value, being investigated separately as well as being accurate.

3.1. *Human Health Indices*

Indices playing role in human health and its affecting routes are divided in three main indices including toxicity effects, physicochemical effects and potential of exposure. Each of the main indices include some subsidiary indices where totally 9 indices are considered for human health. For the physicochemical effects of the waste, corrosion indices, flammability and reactivity indices according to the National Fire Protection Association (NFPA) standards were considered [28]. Toxicity index also was expressed by three subsidiary indices namely instant toxicity, acute toxicity and infectious toxicity. The exposure potential of harmful waste effects consists of two factors: route of effect and duration of effect.

3.2. *Environmental Indices*

Totally 11 indices are considered to estimate the environmental risk of waste. The indices are listed in Table 1. Boundary limits that have been considered for some of the main indices such as eco toxicity are extremely accurate and according to the tracks left by them in the environment (effects on the terrestrial and aquatic species). For instance, the main indices which ATSDR [29] proposed for estimation of toxicity risk are, firstly, not separated for human and environment, and secondly, not comprehensive. The scope of indices which (Liu J, et al. 2014) considered for estimation of toxicity risk in human health do not cover various causes (food, skin and/or breathing). Also in estimation of the environmental toxicity, their subsidiary indices only cover a small group of terrestrial and aquatic species [30]. As the supplement of Table 1. as well as calculation of subsidiary aspects of toxicity affecting human and terrestrial and aquatic species, Tables 2 and 3. are presented respectively.

Table 1. Indices and Scores

Target	Main Indices	Sub-Indices / Abbrev	Route Description	Risk Score
Human Health	Toxicity Effect	Acute / I_1	Based on Table No.2	-
		Chronic / I_2	Carcinogenicity	0.3
				0.2
				0.1
				0
		Infectious / I_3	Viruses	0.3
			Bacteria	0.2
			Fungi	0.1
			-	0
	* Physicochemical-Effects	Corrosivity ((mm/year)) / I_4	pH≤2, pH≥12 or ≥6.35	4
			2 ≤pH≤12 or ≤6.35	0
		Ignitability / I_5	Quickly and easily below the ambient temperature blast case.	4
			The materials have ignited in ambient temperature conditions. (Flash point between 22.8 to 37.8 ° C)	3
			The materials must be heated slowly, to be flammable. (Flash point between 37.8 to 93.5 ° C)	2
			Quickly and easily below the ambient temperature blast case.	
			The materials have ignited in ambient temperature conditions. (Flash point between 22.8 to 37.8 ° C)	
			The materials must be heated slowly, to be flammable. (Flash point between 37.8 to 93.5 ° C)	1
			The materials, special conditions are needed for ignition. (Flash point above 93.5 ° C)	
			Under normal conditions with flammable materials are never not. (Safe up to 820 ° C)	
			The materials under normal conditions never be flammable. (Safe up to 820 ° C)	0

		Reactivity / I_6	Easily able to explosion or decomposition at normal temperatures and pressures	4
			The explosion or decomposition but requires a strong primary energy	3
			Under extreme chemical change in high temperature and pressure	2
			Normally stable, but at a very high temperature and pressure may be active	1
			Normally stable, even under fire exposure	0
	* Exposure Potential	Exposure Route / I_7	Air	0.4
			Soil	0.3
			Surface water	0.2
			Ground water	0.1
		Exposure Time (hr) / I_8	>24	0.4
			12-24	0.3
			6-12	0.2
			1-6	0.1
Environment	Eco toxicity	Terrestrial animals toxicity / I_9	Based on Table No.2	-
		Aquatic toxicity / I_{10}	Based on Table No.3	-
	Bioaccumulation	- / I_{11}	Bio accumulative	0.2
			Non-bio accumulative	0.1
	Physical state	- / I_{12}	Gas	0.4
			Liquid	0.3
			Sludge–slurry	0.2
			Solid	0.1
	Biodegradability	Degree of Waste Destruction (%) / I_{13}	<10	0.4
			>50	0.3
			70-90	0.2
			>90	0.1
	Solubility	Solubility (g/100 ml) / I_{14}	Insoluble	0.4
			<5	0.3
			5–10	0.2
			>50	0.1
	*Quantity	Waste Mass / I_{15} (Kg per mo.)	>10000	4
			10000–5000	3
			5000–1000	2
			<1000	1

* The indices that are identical in human & environment target.

Table 2. The Boolean-based classification of acute toxicity and forms of exposure modes

`	Exposure routes	Medium of carrier	Domain ranges	Risk Score
Human	Inhalation	Gases/vapors	$2 < LC_{50} \leq 20$ mg/l (4 hr)	0.3
			$0.5 < LC_{50} \leq 2$ mg/l (4 hr)	0.2
			$LC_{50} \leq 0.5$ mg/l (4 hr)	0.1
		Gases/vapors	$1 < LC_{50} \leq 5$ mg/l (4 hr)	0.3
			$0.25 < LC_{50} \leq 1$ mg/l (4 hr)	0.2
			$LC_{50} \leq 0.25$ mg/l (4 hr)	0.1
	Intake	Swallowing	$200 < LD_{50} \leq 2000$ mg/kg	0.3
			$25 < LD_{50} \leq 200$ mg/kg	0.2
			$LD_{50} \leq 25$ mg/kg	0.1
	Dermal	Through skin	$400 < LD_{50} \leq 2000$ mg/kg	0.3
			$50 < LD_{50} \leq 400$ mg/kg	0.2
			$LD_{50} \leq 50$ mg/kg	0.1

Table 3. Aquatic chronic toxicity based on L(E)C_{50} values of fish, crustaceans and algae or any other aquatic plants

Sub-Indices	Target Organ	Domain ranges	Risk Score
Aquatic toxicity	Fish [96 h LC_{50} (mg/L)]	≤0.1	0.4
		0.1≤1	0.3
		1 to ≤10	0.2
		10 to ≤100	0.1
	Crustaceans [48 h EC_{50} (mg/L)]	≤0.1	0.4
		1 to ≤10	0.3
		1 to ≤10	0.2
		10 to ≤100	0.1
	Algae [72 or 96 h ErC_{50} (mg/L)]	≤0.1	0.4
		0.1 to ≤1	0.3
		1 to ≤10	0.2
		10 to ≤100	0.1

3.3. *Case Study*

To evaluate the proposed method in this study, a number of 9 wastes in three industries were identified and the initial results were presented in Table 4. The identified wastes owned Certificates of Analysis & Material Safety Data Sheets (MSDS), and their production are clear in kg/month in three industries namely detergents, petrochemical and food.

Table 4. Wastes detected in 3 industrial sector

Industry sector	Waste	Quantity (kg/mo.)	Abbrev
Detergent	Sludge	770	W_1
	Wastewater \ Sulfonation Part	11700	W_2
	Vanadium pentoxide	4000	W_3
	Combined liquid waste	2100	W_4
Petrochemical	Sludge Treatment Plant 1	12000	W_5
	Waste sludge processing unit	14000	W_6
	Sludge Treatment Plant 2	9330	W_7
Food	Sludge treatment plants	2000	W_8
	Regular waste	1000	W_9

In order for rating identified wastes, TOPSIS method was employed and the seven steps were followed using MATLAB R2014a software. The decision matrix of IWRR are presented in Table 5. The column associated to industrial wastes is represented by (W_i , $1 \le i \le 9$) and the row associated to the waste risk indices is represented by (I_i , $1 \le i \le 15$) in the decision matrix. The normalized matrix using Equation 2. and its outputs are reported in Table 6.

Table 5. Decision matrix of IWRR

DM																				
	I_1	I_2	I_3	I_4	I_5	I_6	I_{4*}	I_{5*}	I_{6*}	I_7	I_{7*}	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{15*}
W_1	0.3	0.1	0	0	1	1	0	2	3	0.4	0.1	0.4	0.1	0.3	0.2	0.2	0.3	0.3	1	1
W_2	0.2	0.2	0	0	2	2	0	3	1	0.4	0.4	0.4	0.1	0.2	0.2	0.3	0.2	0.2	4	4
W_3	0.3	0.3	0	4	4	3	4	4	3	0.1	0.4	0.2	0.1	0.2	0.1	0.1	0.2	0.3	2	2
W_4	0.2	0.2	0	4	3	2	0	3	2	0.3	0.1	0.4	0.1	0.3	0.2	0.3	0.3	0.3	2	2
W_5	0.1	0.1	0	0	2	2	0	4	2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.1	0.1	4	4
W_6	0.2	0.2	0	0	3	3	0	2	1	0.4	0.3	0.4	0.4	0.2	0.1	0.2	0.1	0.1	4	4
W_7	0.3	0.1	0	0	2	2	0	2	2	0.2	0.2	0.4	0.1	0.3	0.1	0.2	0.1	0.1	3	3
W_8	0	0	0	0	1	1	0	2	1	0.3	0.2	0.2	0	0	0.1	0.2	0.1	0.1	2	2
W_9	0	0	0	0	0	1	0	0	1	0.4	0.1	0.2	0	0	0.1	0.2	0.1	0.1	1	1

Table 6. Normalized decision matrix

	DM																			
	I_1	I_2	I_3	I_4	I_5	I_6	I_{4*}	I_{5*}	I_{6*}	I_7	I_{7*}	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{15*}
W_1	0.47	0.20	1.00	0.00	0.14	0.16	0.00	0.25	0.51	0.42	0.13	0.40	0.21	0.46	0.44	0.30	0.54	0.50	0.12	0.12
W_2	0.32	0.41	0.00	0.00	0.29	0.33	0.00	0.37	0.17	0.42	0.53	0.40	0.21	0.30	0.44	0.46	0.36	0.33	0.47	0.47
W_3	0.47	0.61	0.00	0.71	0.58	0.49	1.00	0.49	0.51	0.10	0.53	0.20	0.21	0.30	0.22	0.15	0.36	0.50	0.24	0.24
W_4	0.32	0.41	0.00	0.71	0.43	0.33	0.00	0.37	0.34	0.31	0.13	0.40	0.21	0.46	0.44	0.46	0.54	0.50	0.24	0.24
W_5	0.16	0.20	0.00	0.00	0.29	0.33	0.00	0.49	0.34	0.21	0.27	0.30	0.21	0.30	0.44	0.30	0.18	0.17	0.47	0.47
W_6	0.32	0.41	0.00	0.00	0.43	0.49	0.00	0.25	0.17	0.42	0.40	0.40	0.85	0.30	0.22	0.30	0.18	0.17	0.47	0.47
W_7	0.47	0.20	0.00	0.00	0.29	0.33	0.00	0.25	0.34	0.21	0.27	0.40	0.21	0.46	0.22	0.30	0.18	0.17	0.36	0.36
W_8	0.00	0.00	0.00	0.00	0.14	0.16	0.00	0.25	0.17	0.31	0.27	0.20	0.00	0.00	0.22	0.30	0.18	0.17	0.24	0.24
W_9	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.17	0.42	0.13	0.20	0.00	0.00	0.22	0.30	0.18	0.17	0.12	0.12

In order to calculate the normalized weighted matrix, calculation of the weight of each index in rating the waste risk is required. Shannon entropy as a popular method (described through Equations 9 to 11) is used to estimate the weight of each of 20 indices of industrial wastes and finally three factors e_i, d_i and w_i for each index are presented in Table 7. Among these indices, $I_{3,4*}$ and I_{12} were evaluated as the maximum and minimum weights among the selected indices.

Table 7. Calculated entropy measure, divergence and objective weights of criteria

	I_1	I_2	I_3	I_4	I_5	I_6	I_{4*}	I_{5*}	I_{6*}	I_7	I_{7*}	I_8	I_9	I_{10}	I_{11}	I_{12}	I_{13}	I_{14}	I_{15}	I_{15*}
e_j	0.86	0.85	0.00	0.32	0.90	0.96	0.00	0.93	0.96	0.97	0.94	0.98	0.80	0.88	0.97	0.98	0.95	0.94	0.95	0.95
d_j	0.14	0.15	1.00	0.68	0.10	0.04	1.00	0.07	0.04	0.03	0.06	0.02	0.20	0.12	0.03	0.02	0.05	0.06	0.05	0.05
w_j	0.04	0.04	0.26	0.17	0.02	0.01	0.26	0.02	0.01	0.01	0.02	0.01	0.05	0.03	0.01	0.00	0.01	0.02	0.01	0.01

Using the results of previous steps and using Equations 3 to 7, positive ideal solution (PIS) and negative ideal solution (NIS) were calculated. The closeness factor of each solution, as the risk value of each of the identified industrial waste in the industrial section, also were calculated using TOPSIS method and the results were presented in Table 8. According to the results, waste no 3 (Vanadium pentoxide) from the detergents group, and waste no 9 (Regular waste) from the food group were determined as the most and least risky wastes, respectively. Figure 2. shows another type of ranking identified industrial waste risk.

Table 8. Closeness coefficient table & ranking wastes

Industrial Wastes	S^+	S^-	RS	Ranking
W_1	0.257	0.286	0.473	2
W_2	0.028	0.383	0.069	5
W_3	0.286	0.257	0.526	1
W_4	0.127	0.363	0.260	3
W_5	0.022	0.383	0.055	7
W_6	0.052	0.382	0.119	4
W_7	0.028	0.383	0.068	6
W_8	0.007	0.386	0.017	8
W_9	0.003	0.386	0.007	9

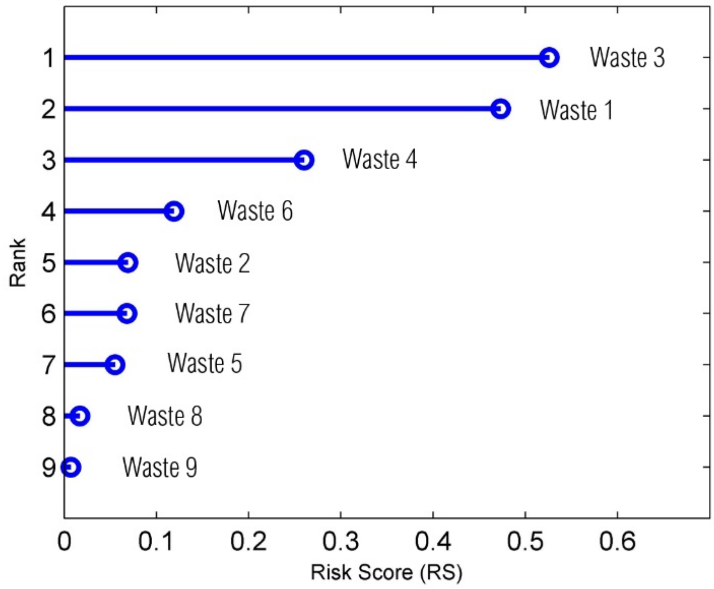

Figure 2. Ranking of 9 industrial wastes with TOPSIS method

4. Conclusion

Methods of IWRR are formed of two parts: identifying indices, and the calculation method/algorithm. Minding the applicability, complexity, computational costs and extraction of proper indices in order to define the IWRR are important to be considered. In this study, a number of 9 indices over the human health, and 11 indices over the environment risk were identified, extracted and their boundary limits were determined. Separation of indices and risk values by human and environment might give useful information to industry owners of various sections. In the following, the multi-criteria decision-making method (TOPSIS) was developed for IWRR. Conventional MCDM methods focus on a set of possible solutions and consider more than only one criterion to determine rating priority in a system. Among the dual purposes of this research, the main goal is to develop TOPSIS method for rating IWRR among the identified wastes in three industry sections. This was described using a multi-criteria decision-making method under uncertainty situations.

5. References

[1] United Nations Department of Economic and Social Affairs (UN DESA) (2014) World Urbanization Prospects: The 2014 Revision, Highlights. New York: United Nations.

[2] Storey, Donovan, Lorenzo Santucci, Rowan Fraser, Joao Aleluia, and Laksiri Chomchuen. "Designing effective partnerships for waste-to-resource initiatives: Lessons learned from developing countries." Waste Management & Research 33, no. 12 (2015): 1066-1075.

[3] Musee, N., L. Lorenzen, and Chris Aldrich. "An aggregate fuzzy hazardous index for composite wastes." Journal of hazardous materials 137, no. 2 (2006): 723-733.

[4] Broadhurst, J. L., and J. G. Petrie. "Ranking and scoring potential environmental risks from solid mineral wastes." Minerals Engineering 23, no. 3 (2010): 182-191.

[5] Zitko, V. "Priority ranking of chemicals for risk assessment." Science of the total environment 92 (1990): 29-39.

[6] Mitchell, Rachel R., Cheryl L. Summer, Shari A. Blonde, Dennis M. Bush, Gary K. Hurlburt, Erin M. Snyder, and John P. Giesy. "SCRAM: a scoring and ranking system for persistent, bioaccumulative, and toxic substances for the North American Great Lakes-resulting chemical scores and rankings." Human and Ecological Risk Assessment: An International Journal 8, no. 3 (2002): 537-557.

[7] Hauschild, Veronique D., and Gary M. Bratt. "Prioritizing industrial chemical hazards." Journal of Toxicology and Environmental Health, Part A 68, no. 11-12 (2005): 857-876.

[8] Shin, Saemi, Hyung-Il Moon, Kwon Seob Lee, Mun Ki Hong, and Sang-Hoon Byeon. "A chemical risk ranking and scoring method for the selection of harmful substances to be specially controlled in occupational environments." International journal of environmental research and public health 11, no. 11 (2014): 12001-12014.

[9] Hauschild, Veronique D., and Gary M. Bratt. "Prioritizing industrial chemical hazards." Journal of Toxicology and Environmental Health, Part A 68, no. 11-12 (2005): 857-876.

[10] Talınlı, İlhan, Rana Yamantürk, Egemen Aydın, and Sibel Başakçılardan-Kabakçı. "A rating system for determination of hazardous wastes." Journal of hazardous materials 126, no. 1 (2005): 23-30.

[11] Rao, K. Rajeshwar, S. Venkateswar Rao, and V. Chary. "Estimation of risk indices of chemicals during transportation." Process safety progress 23, no. 2 (2004): 149-154.

[12] Pourahmadi, Amirali, Taghi Ebadi, and Manouchehr Nikazar. "Development a Conceptual Framework for Industrial and Hazardous Wastes Rating Systems." Civil Engineering Journal 2, no. 4 (2016): 140-149.

[13] Musee, N., Chris Aldrich, and L. Lorenzen. "New methodology for hazardous waste classification using fuzzy set theory: Part II. Intelligent decision support system." Journal of hazardous materials 157, no. 1 (2008): 94-105.

[14] Musee, N., L. Lorenzen, and C. Aldrich. "New methodology for hazardous waste classification using fuzzy set theory: Part I. Knowledge acquisition." Journal of hazardous materials 154, no. 1 (2008): 1040-1051.

[15] Al-Sharrah, Ghanima. "Ranking using the Copeland score: a comparison with the Hasse diagram." Journal of chemical information and modeling 50, no. 5 (2010): 785-791.

[16] Lerche, Dorte, Peter B. Sørensen, Henrik Sørensen Larsen, Lars Carlsen, and Ole John Nielsen. "Comparison of the combined monitoring-based and modelling-based priority setting scheme with partial order theory and random linear extensions for ranking of chemical substances." Chemosphere 49, no. 6 (2002): 637-649.

[17] Swanson, Mary B., Gary A. Davis, Lori E. Kincaid, Terry W. Schultz, John E. Bartmess, Sheila L. Jones, and Emma Lou George. "A screening method for ranking and scoring chemicals by potential human health and environmental impacts." Environmental Toxicology and Chemistry 16, no. 2 (1997): 372-383.

[18] García-Cascales, M. Socorro, and M. Teresa Lamata. "On rank reversal and TOPSIS method." Mathematical and Computer Modelling 56, no. 5 (2012): 123-132.

[19] C. L. Hwang and K. Yoon, Multiple Attribute Decision Making, Springer, Berlin, Germany, 1981.

[20] García-Cascales, M. Socorro, and M. Teresa Lamata. "Solving a decision problem with linguistic information." Pattern Recognition Letters 28, no. 16 (2007): 2284-2294.

[21] Boran, Fatih Emre, Serkan Genç, Mustafa Kurt, and Diyar Akay. "A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method." Expert Systems with Applications 36, no. 8 (2009): 11363-11368.

[22] Milani, A. S., A. Shanian, R. Madoliat, and J. A. Nemes. "The effect of normalization norms in multiple attribute decision making models: a case study in gear material selection." Structural and multidisciplinary optimization 29, no. 4 (2005): 312-318.

[23] Yang, Taho, and Pohung Chou. "Solving a multiresponse simulation-optimization problem with discrete variables using a multiple-attribute decision-making method." Mathematics and Computers in simulation 68, no. 1 (2005): 9-21.

[24] Shannon, Claude E., and Warren Weaver. "The mathematical theory of communication. Urbana, Ill." Univ. Illinois Press 1 (1949): 17.

[25] Zeleny, Milan, and James L. Cochrane. "A priori and a posteriori goals in macroeconomic policy making." Multiple Criteria Decision Making 373 (1973): 391.

[26] Shemshadi, Ali, Hossein Shirazi, Mehran Toreihi, and Mohammad J. Tarokh. "A fuzzy VIKOR method for supplier selection based on entropy measure for objective weighting." Expert Systems with Applications 38, no. 10 (2011): 12160-12167.

[27] Wang, Tien-Chin, and Hsien-Da Lee. "Developing a fuzzy TOPSIS approach based on subjective weights and objective weights." Expert Systems with Applications 36, no. 5 (2009): 8980-8985.

[28] National Fire Protection Association (NFPA), Standard 325A, Fire hazard properties of flammable liquids, gases and volatile solids, Hazardous Chemicals Data, NFPA, Quincy, MA, 1994.

[29] CHLORIDE, V. (2016). Agency for Toxic Substances and Disease Registry Division of Toxicology and Human Health Sciences Atlanta, GA 30329-4027 January 2016.

[30] Liu, Jining, Chen Tang, Deling Fan, Lei Wang, Linjun Zhou, and Lili Shi. "Ranking and screening hazardous chemicals for human health in southeast China." Organic Chemistry: Current Research 3, no. 1 (2014): 1.